"TECH NOTES"

"TECH NOTES" is an effort by the FOSSC Materials Laboratory to share design and construction technology gained from projects done throughout WSDOT. This issue is from the Pavements Branch discussing temperature and density differentials.

Temperature Differentials and the Related Density Differentials in Asphalt Concrete Pavement Construction

The WSDOT has found that the cyclic pattern of low density, open-texture areas in Asphalt Concrete Pavement (ACP), which prematurely fail by fatigue cracking, raveling, or both, directly relate to the thermal differentials found during construction.

The Problem

The cyclic pattern of open-texture areas appearing on a large number of WSDOT's hot-mix asphalt (HMA) paving projects can be attributed to thermal differentials. Thermal differentials are formed during transport of the HMA (Figure 1) to the paving project and can result in lower than desirable mix compaction temperatures. The cooler HMA formed during transport is placed in concentrated areas in the mat which are near cessation temperature and tend to resist adequate compaction (Figure 2). These concentrated areas of cooler material usually have higher air voids along with an open surface texture that are more susceptible to deterioration by traffic and the environment.

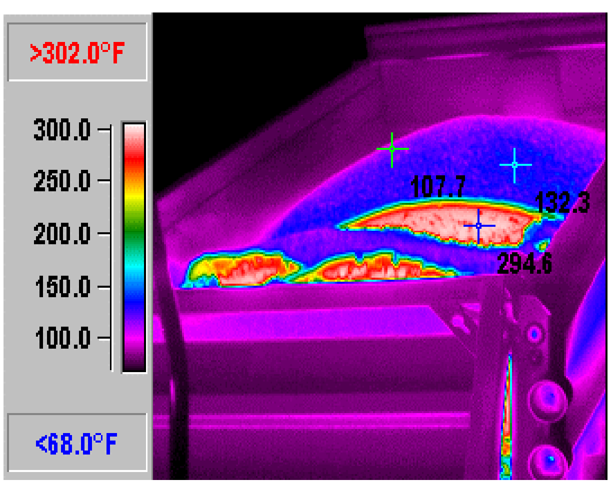

Figure 1. Haul vehicle dumping into paver.

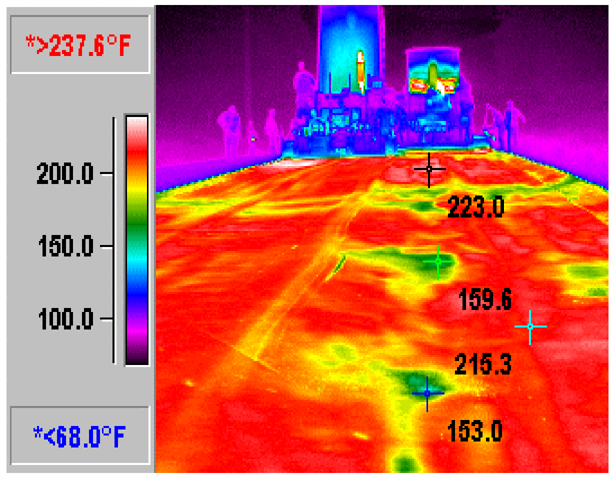

Figure 2. Cyclic pattern of cool areas in mat.

Solution

This research began in 1995 when it was found that large temperature differentials existed in the mat after placement. Nuclear density checks showed that these cooler areas of mix exhibited lower densities than the rest of the mat.

In 1998, this research was continued to examine the exact cause of these cooler areas. An infrared camera was used to determine the location of these cool areas in the mat, then mix samples were taken in these areas and adjacent "normal" temperature areas to test for mix properties (including aggregate segregation). Nuclear density testing was also performed in similar areas where sampling was not being done. It was determined that these cool areas did not have, in general, the symptoms of aggregate segregation, but did have higher air voids.

The 1999 construction season consisted of 35 projects viewed with an infrared camera, and detailed data collected to determine any patterns between different operations or project factors (including, but not limited to, materials transfer devices/vehicles, pavers, roller operations, air and surface temperatures, etc.). There was a wide array of remixing devices used, but when actual remixing of the HMA before placement did occur, temperature differentials were reduced, and in some cases, almost eliminated (mat temperature differentials less than 10°F). Some of the devices that are classified as remixing machines were inconsistent in their production of a uniform temperature mat, and others that were not classified as remixing machines had the ability to reduce temperature differentials. A general relationship between increasing temperature differentials and increasing air voids was found.

The 2000 study concentrated on determining if a density profile procedure could locate potential areas of low density, test for density differentials, and ultimately be used as a quality control procedure to minimize the occurrence of density differentials. It was found that the density profile procedure has the ability to locate and test for density differentials during construction. It was also found that pavements that experienced considerable temperature differentials produced substantial density differentials.

Density profiles have been conducted in Kansas to control density differentials caused by aggregate segregation for the past ten years and more recently in Texas to combat aggregate segregation and temperature differentials. WSDOT used density profiles during the 2000 construction season on 17 projects to determine the effectiveness of the procedure in detecting low-density areas caused by either aggregate segregation or thermal differentials. It was found that this procedure works well in determining where low-density areas exist and the extent of the density differentials. Figure 3 is an infrared image of a mat with a temperature differential less than 25°F. The corresponding density differentials are minimal. Figure 4 is an infrared image of a mat with a temperature differential greater than 25°F. The corresponding density differentials exceed the criteria.

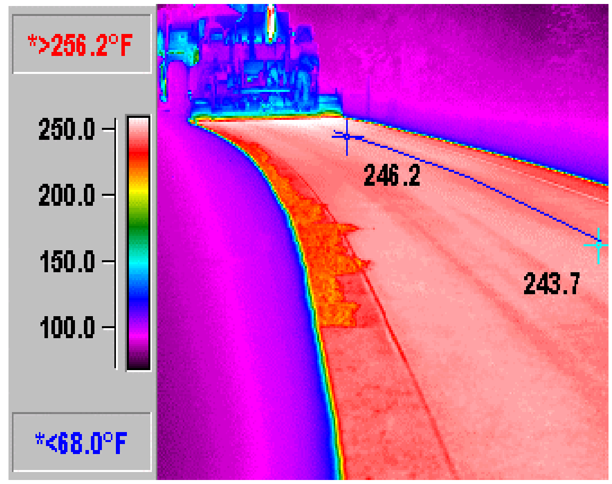

Figure 3. Infrared image from passing density profile.

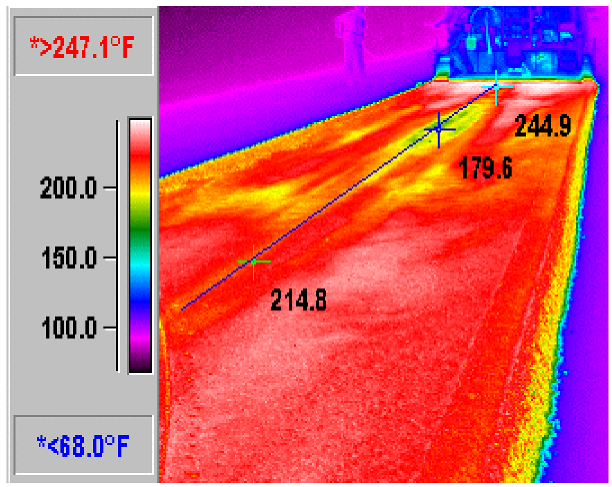

Figure 4. Infrared image from failing density profile.

The breakpoint criterion used for the 2000 study was a temperature differential of 25°F or greater, a maximum density range (maximum – minimum) of 6.0 lb/ft^3, and a maximum density drop (mean – minimum) of 3.0 lb/ft^3. The location of the density profiles are determined by either temperature differentials exceeding the criterion or visible aggregate segregation. The profile is then started approximately 10 feet behind the cool area in the case of temperature differentials or on a 2 feet skew for longitudinal aggregate segregation. Nuclear density tests are taken every 5 feet for a total of 50 feet and the density range and drop are calculated.

A further explanation of what the criteria for the density range and drop actually correspond to in percent air voids are summarized in Table 1. For instance, assuming a maximum theoretical "rice" density of 155.0 lb/ft^3, each 3.0 lb/ft^3 drop from nominal percent air voids results in approximately a 2 percent increase in air voids. The long-term average for percent of rice density in Washington State is 93.1 percent, which results in an air void content of 6.9 percent. If 3.0 lb/ft^3 were subtracted from this long-term average (in accordance with one of the two density criteria), the resultant air void content would be 8.9 percent and if 6.0 lb/ft^3 were subtracted (which is approximately ½ the maximum density range we have observed), the air void content would be 10.8 percent. This is a significant difference of in-place density.

Table 1. Resultant Air Void Content.

Percent of Rice	**Mix Air Voids**		
	@ Mean	**@ Mean – 3.0 lb/ft^3**	**@ Mean – 6.0 lb/ft^3**
95%	5%	7%	9%
94%	6%	8%	10%
93%	7%	9%	11%
92%	8%	10%	12%
91%	9%	11%	13%

The temperature criterion of 25°F or greater was set using data collected in 1999. In general, WSDOT found that with ΔT's greater than 25°F, the in-place air voids increased by approximately 2 percent. WSDOT used this criterion during the 2000 construction season to determine when density profiles were to be performed. The results of the 69 profiles taken in 2000 show that temperature differentials of 25°F or greater result in failing density profiles approximately 90 percent of the time and, conversely where temperature differentials are less than 25°F, approximately 80 percent of the density profiles pass the density criteria (Table 2). The resulting 10 and 20 percent, respectively, could possibly be attributed to job specific conditions, varying or inadequate roller patterns, or equipment usage.

The transfer devices seen during the 1999 and 2000 paving seasons are summarized in Table 3 and classified by the typical mat temperature differential seen during paving.

Table 2. Percent Pass and Fail Density Criteria According to Temperature Differentials.

	ΔT ≥ 25°F	ΔT < 25°F
Number of Profiles	28	41
Failed both density criteria	20	4
Passed both density criteria	3	33
Failed only high - low	3	2
Failed only mean - low	2	2
Percent passing	10.7	80.5
Percent failing	89.3	19.5

Table 3. Temperature Differential Results According to Transfer Devices.

Equipment	Number of Projects with Typical ΔT		
	≤25°F	>25°F	Total
No MTV	0	9	9
Blaw-Knox MC-30	3	9	11
Paddles operating	3	4	
Paddles not operating	0	4	
Roadtec Shuttle Buggy	10	1	11
Cedarapids MS-3	1	1	2
Windrow Elevator	13	5	18
Cedarapids MS-2	9	3	
Other Windrow Elevator	4	2	
CMI MTP-400	1	0	1
Windrow Elevator/MC-30	1	0	1

Currently, WSDOT uses random testing (5 tests per 400-ton lot) for Quality Assurance (QA) of HMA compaction. For a typical 2-inch overlay that is one lane wide, a 400-ton lot covers approximately six-tenths of a mile, which means that only 5 tests are being performed within this length. After evaluation of the Quality Assurance results, it was found that the low-density areas that may exist in the mat are not adequately captured with random testing. Therefore, the quality assurance testing program does not take into account the substantial effect density differentials can have on HMA. The random test results compared with the results from the density profiles show that the cooler temperature areas could easily be missed during QA testing. A worst case scenario can have temperature differentials that occur every 120 feet apart, which equates to approximately 25 locations of possible low-density areas per 400-ton lot. With density profiles, these cooler temperature areas can be found (if they exist), tested to determine if they affect the density of the mat, and hopefully minimized or eliminated.

Implementation

The results of the 2000 study prompted a meeting with the Asphalt Paving Association of Washington (APAW), Contractors, and State personnel to implement the density profile procedure as a shadow specification in the 2001 construction season. A Joint Task Force was assembled and met on March 12, 2001. The results of this meeting were:

- Perform the density profile procedure on all jobs consisting of ≥ 2,500 tons of hot mix
- Temperature and density profiles will be performed by a combination of WSDOT and Contractor personnel (specific tasks to be determined on each project within the team)
- Temperature profiles – team will perform a minimum of 2 per 400-ton lot
- Density profiles – team will perform a minimum of 2 per day in an area with $\Delta T \geq 25^{o}F$ and a minimum of 1 per day in an area with $\Delta T < 25^{o}F$ (no density profiles to be performed the first day of paving or until roller pattern has been established)
- Training will be provided if needed, test procedure is available from contact below
- Infrared temperature guns will be purchased by each DOT Project Office (a preferred temperature gun has been identified and will be recommended but not required)
- Team may vary the operations to try and IMPROVE (i.e., reduce) temperature and density differentials
  - Operations should not be changed if project is achieving a $\Delta T < 25^{o}F$
  - Collect temperature and density data and also record specific information such as ambient temperature, paving equipment, etc.
- All collected data is to be shared equally between the WSDOT and the Contractor

The full implementation of the density profile procedure is dependent on the results of the shadow specification that will be performed in 2001. This shadow specification will allow each Contractor and DOT project office to determine the effect temperature has or can have on a specific paving project in terms of density. It will allow the paving crews to determine if temperature differentials occur and if so, is the finished product affected by non-uniform density. This work is being done without any risk to the paving operations, and there are no incentives or disincentives.

There are a few options for implementation, including how they will be performed (i.e. quality control or for payment) and what the incentives or penalties will be for either achieving uniform densities or having density differentials. All the information collected during the 2001 construction season will be shared equally between the contractors and WSDOT. This data will have a direct impact on the decisions made for the 2002 paving season.

Benefits

The expected benefit of this research is to lengthen the pavement life by providing a more uniform density. Achieving uniform densities around 93 percent of maximum theoretical density throughout the entire project can hopefully extend the life of the pavement to at least the design life of 15 years for a rehabilitation project. If 7 percent air voids are achieved and there are minimal density differentials, there is a greater chance of the pavement lasting its design life because the effects of traffic loading (fatigue cracking, raveling) and the environment (oxidation of the binder, permeability) will not be able to attack any low-density areas and cause rehabilitation to take place earlier than expected.

Products Available

An infrared imagebase that holds all of the infrared images and project details can be found at: http://www.wsdot.wa.gov/fossc/mats/pavement/sptc.htm
A research report is also available.

For More Information

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